CLAIMS

We claim:

1. A system comprising:

a wavelet-based image processing path to enhance an input image in a wavelet domain; and

a print engine coupled to the processing path.

2. The system defined in Claim 1 wherein the image processing path comprises:

a forward wavelet transform;

one or more wavelet-based processing blocks; and

an inverse wavelet transform.

3. The system defined in Claim 2 wherein the forward wavelet transform comprises a critically sampled wavelet transform.

4. The system defined in Claim 2 wherein the forward wavelet transform comprises an overcomplete wavelet transform.

5. The system defined in Claim 2 wherein the forward wavelet transform comprises a Haar wavelet transform.

6. A system defined in Claim 2 wherein the forward wavelet transform comprises a 5,3 wavelet transform.

7. A system defined in Claim 2 wherein the forward wavelet transform comprises a 2,6 wavelet transform.

8. A system defined in Claim 2 wherein the forward wavelet transform comprises a complex wavelet transform.

9. A system defined in Claim 2 wherein the forward wavelet transform comprises a limited redundancy wavelet transform.

10. The system defined in Claim 1 wherein the image processing path comprises:

a forward wavelet transform;

a denoising processing block coupled to the forward wavelet transform to perform denoising based on at least one given threshold; and

an inverse wavelet transform.

11. The system defined in Claim 10 wherein the denoising processing block sets coefficients below the at least one given threshold to a predetermined value less than the threshold.

12. The system defined in Claim 11 wherein the at least one given threshold is calculated based on the presence of additive Gaussian white noise in an image.

13. The system defined in Claim 11 wherein the at least one given threshold is calculated from a series of test images.

14. The system defined in Claim 11 wherein the at least one given threshold comprises different thresholds applied to different levels of decomposition.

15. The system defined in Claim 11 wherein the at least on given threshold comprises different thresholds are applied to different bands.

16. The system defined in Claim 11 wherein the at least one given threshold is set manually.

17. The system defined in Claim 11 wherein the at least one given threshold is set based on the standard deviation or medium of absolute values of coefficients in the region.

18. The system defined in Claim 17 wherein the at least one given threshold is set on the standard deviation of HH coefficients at level one.

19. The system defined in Claim 11 wherein the at least one given threshold is set in the standard deviation or medium of absolute values of HH coefficients at each level.

20. The system defined in Claim 11 wherein the at least one given threshold is set based on the standard deviation or medium of absolute

values of H/HL/HH coefficients at a first level at a particular level to create a band dependent threshold.

21. The system defined in Claim 11 wherein the at least one given threshold is set based on a standard deviation or medium of absolute values of LH/HL/HH coefficients at each level.

22. The system defined in Claim 11 wherein the at least one given threshold is set manually using controls on a user interface.

23. The system defined in Claim 11 wherein the at least one given threshold is set by computing local variances/mediums of coefficients in between a band.

24. The system defined in Claim 11 wherein the at least one given threshold is set using a classifier.

25. The system defined in Claim 11 wherein the denoising processing block sets all coefficients below the at least one given threshold to zero.

26. The system defined in Claim 1 wherein the image processing path comprises:

a forward wavelet transform;

a sharpening or smoothing processing block coupled to the forward wavelet transform to sharpen or smooth coefficients based on the magnitude of individual coefficients; and

an inverse wavelet transform.

27. The system defined in Claim 26 wherein the sharpening or smoothing processing block multiplies wavelet coefficients with a scale dependent factor.

28. The system defined in Claim 27 wherein the scale-dependent factor comprises:

$$\mu_j = R \cdot 2^{\alpha j}$$

where R is a renormalization factor and α is the parameter that determines the degree of sharpening or smoothing.

29. The system defined in Claim 26 wherein the sharpening or smoothing processing block normalizes coefficients after sharpening or smoothing.

30. The system defined in Claim 28 wherein the sharpening or smoothing processing block uses a scale dependent factor that is selected to include normalization.

31. The system defined in Claim 1 wherein the image processing path comprises a linear interpolation filter that is applied to wavelet coefficients.

32. The system defined in Claim 31 wherein the image processing path comprises:

an inverse wavelet transform to inverse transform coefficients down to a predetermined level;

a downsampling block coupled to the inverse wavelet transform to downsample wavelet coefficients.

33. The system defined in Claim 32 wherein the downsampling block performs either a deterministic or random downsampling based on coefficient size at the predetermined level.

34. The system defined in Claim 32 wherein the downsampling block uses at least one interpolation filter based on a value of a coefficient with respect to a predetermined threshold.

35. The system defined in Claim 34 wherein the at least one interpolation filter comprises a Key's filter.

36. The system defined in Claim 34 wherein the downsampling processing block applies a smoothing filter to wavelet coefficients that are smaller than a first threshold and a sharpening filter to wavelet coefficients that are larger than a second threshold.

37. The system defined in Claim 1 wherein the image processing path comprises:

a forward wavelet transform;

a denoising processing block coupled to the forward wavelet transform to perform denoising based on a given threshold;

a sharpening or smoothing processing block coupled to the denoising processing block to sharpen or smooth coefficients based on the magnitude of individual coefficients;

an inverse wavelet transform coupled to the sharpening or smoothing processing block; and

a downsampling block coupled to the inverse wavelet transform to downsample wavelet coefficients.

38. The system defined in Claim 1 further comprising an input operable to receive the input image from an external source and a scanner for generating the input image, wherein the input and the scanner are coupled to the image processing path.

39. A method comprising:

processing an input image by enhancing the input image, including applying a forward wavelet transorm to create a plurality of coefficients and filtering coefficients with a coefficient domain operator in a wavelet domain; and

outputting a processed image.

40. The method defined in Claim 39 further comprising:

applying one or more wavelet-based processing blocks to coefficients resulting from applying the forward wavelet transform; and

applying an inverse wavelet transform.

41. The method defined in Claim 40 wherein the forward wavelet transform comprises a critically sampled wavelet transform.

42. The method defined in Claim 40 wherein the forward wavelet transform comprises an overcomplete wavelet transform.

43. The method defined in Claim 40 wherein the forward wavelet transform comprises a Haar wavelet transform.

44. A system defined in Claim 40 wherein the forward wavelet transform comprises a 5,3 wavelet transform.

45. A system defined in Claim 40 wherein the forward wavelet transform comprises a 2,6 wavelet transform.

46. A system defined in Claim 40 wherein the forward wavelet transform comprises a complex wavelet transform.

47. A system defined in Claim 40 wherein the forward wavelet transform comprises a limited redundancy wavelet transform.

48. The method defined in Claim 39 further comprising:

performing denoising on the plurality of coefficients based on a given threshold; and

applying an inverse wavelet transform on the plurality of coefficients after denoising.

49. The method defined in Claim 1 wherein performing denoising comprises setting coefficients below the at least one given threshold to a predetermined value.

50. The system defined in Claim 49 wherein the at least one given threshold is calculated based on the presence of additive Gaussian white noise in an image.

51. The system defined in Claim 49 wherein the at least one given threshold is calculated from a series of test images.

52. The system defined in Claim 49 wherein the at least one given threshold comprises different thresholds are applied to different levels of decomposition.

53. The system defined in Claim 49 wherein the at least one given threshold comprises different thresholds are applied to different bands.

54. The system defined in Claim 49 wherein the at least one given threshold is set manually.

55. The system defined in Claim 49 wherein the at least one given threshold is set based on the standard deviation or medium of absolute values of coefficients in the region.

56. The system defined in Claim 55 wherein the at least one given threshold is set on the standard deviation of HH coefficients at level one.

57. The system defined in Claim 49 wherein the at least one given threshold is set in the standard deviation or medium of absolute values of HH coefficients at each level.

58. The system defined in Claim 49 wherein the at least one given threshold is set based on the standard deviation or medium of absolute values of H/HL/HH coefficients at a first level at a particular level to create a band dependent threshold.

59. The system defined in Claim 49 wherein the at least one given threshold is set based on a standard deviation or medium of absolute values of LH/HL/HH coefficients at each level.

60. The system defined in Claim 49 wherein the at least one given threshold is set manually using controls on a user interface.

61. The system defined in Claim 49 wherein the at least one given threshold is set by computing local variances/mediums of coefficients in between a band.

62. The system defined in Claim 49 wherein the at least one given threshold is set using a classifier.

63. The method defined in Claim 49 wherein performing denoising comprises setting all coefficients below the at least one given threshold to zero.

64.. The method defined in Claim 39 further comprising:

sharpening or smoothing coefficients based on the magnitude of individual coefficients; and

applying an inverse wavelet transform on the plurality of coefficients after sharpening or smoothing.

65. The method defined in Claim 64 wherein sharpening or smoothing comprises multiplying wavelet coefficients with a scale dependent factor.

66. The method defined in Claim 65 wherein the scale-dependent factor comprises:

$$\mu_j = R \cdot 2^{\alpha j}$$

where R is a renormalization factor and α is the parameter that determines the degree of sharpening or smoothing.

67. The method defined in Claim 64 wherein sharpening or smoothing comprises normalizing coefficients.

68. The method defined in Claim 39 further comprising applying a linear interpolation filter to wavelet coefficients.

69. The method defined in Claim 39 further comprising:

applying an inverse wavelet transform to inverse transform coefficients down to a predetermined level; and

downsampling wavelet coefficients.

70. The method defined in Claim 69 wherein downsampling the wavelet coefficients comprises performing either a deterministic or random sampling based on coefficient size at the predetermined level.

71. The method defined in Claim 69 wherein downsampling wavelet coefficients comprises using at least one interpolation filter based on a value of a coefficient with respect to a predetermined threshold.

72. The method defined in Claim 71 wherein the at least one interpolation filter comprises a Key's filter.

73. The method defined in Claim 69 wherein downsampling comprises applying a smoothing filter to wavelet coefficients that are smaller than a first threshold and a sharpening filter to wavelet coefficients that are larger than a second threshold.

74. The method defined in Claim 39 further comprising:

performing denoising on coefficients of the plurality of coefficients based on a given threshold;

sharpening or smoothing coefficients of the plurality of coefficients based on the magnitude of individual coefficients; and

applying an inverse wavelet transform to the plurality of coefficients and downsampling wavelet coefficients.

75. A system comprising:

an image enhancement subsystem having a classifier to control one or more of the following: denoising, sharpening, smoothing, halftoning, under color removal; and

an output coupled to the image enhancement subsystem.

76. The system defined in Claim 75 wherein the image enhancement subsystem operates, at least in part, in the wavelet domain.

77. A method comprising:

computing a classifier;

selecting different denoising thresholds for halftone and text regions of an image based on the classifier.

78. The method defined in Claim 77 wherein computing the classifier comprises computing the classifier from wavelet coefficients.

79. The method defined in Claim 78 wherein computing a classifier comprises computing a standard deviation of wavelet coefficients in different bands.

80. The method defined in Claim 78 wherein computing a classifier comprises computing a standard deviation of wavelet coefficients in different decomposition levels.

81. The method defined in Claim 78 wherein computing a classifier comprises computing a standard deviation of wavelet coefficients across different bands.

82. The method defined in Claim 78 wherein computing a classifier comprises computing a first absolute movement.

83. The method defined in Claim 78 further comprising:

computing a standard deviation of wavelet coefficients; and

applying different denoising and sharpening/smoothing parameters to wavelet coefficients in text halftone and background regions of image data.

84. A method comprising:

applying a forward wavelet transform to image data:

performing denoising by thresholding coefficients generated by applying the forward wavelet transform;

rescaling coefficients by filtering coefficients after thresholding.

85. The method defined in Claim 84 further comprising sampling the wavelet coefficients.

86. The method defined in Claim 84 further comprising applying an inverse wavelet transform on filtered coefficients.

87. The method defined in Claim 84 wherein scaling coefficients comprises performing sharpening or smoothing by multiplying coefficients with a level dependent parameter.

88. The method defined in Claim 87 wherein high frequency bands are multiplied with a larger factor than low frequency bands to perform sharpening.

89. The method defined in Claim 87 wherein low frequency bands are multiplied by a larger factor than the high frequency bands to perform smoothing.

90. The method defined in Claim 88 wherein rescaling coefficients comprises filtering LL band coefficients with a high pass filter.

91. The method defined in Claim 89 wherein rescaling coefficients comprises filtering LL band coefficients with a low pass filter.

92. The method defined in Claim 84 further comprising filtering of a subband at a specific level decomposition to modify the subband.

93. The method defined in Claim 92 further comprising filtering the LL component at the largest decomposition level with a sharpening filter.

94. The method defined in Claim 92 further comprising filtering the LL component at the largest decomposition level with a smoothing filter.

95. The method defined in Claim 84 wherein filtering coefficients comprises removing periodic patterns in a specific band by applying a filter to the specific band.

96. The method defined in Claim 95 wherein the filter comprises a band pass filter.

97. The method defined in Claim 95 wherein the filter comprises a notch filter.

98. The method defined in Claim 84 wherein the period is 3.

99. The method defined in Claim 84 wherein the period is 5.

100. The method defined in Claim 84 further comprising performing halftoning.

101. The method defined in Claim 100 wherein performing halftoning comprises adding white noise with a scaled dependent variance to wavelet coefficients.

102. The method defined in Claim 100 wherein performing halftoning comprises adding white noise with a subband dependent variance to wavelet coefficients.

103. The method defined in Claim 84 further comprising resampling image data.

104. The method defined in Claim 103 further comprising performing an inverse wavelet transform.

105. The method defined in Claim 104 wherein performing resampling image data and performing inverse wavelet transform are performed simultaneously by performing resampling directly on wavelet coefficients.

106. The method defined in Claim 105 wherein the resampling is performed using an interpolation filter.

107. The method defined in Claim 106 wherein the interpolation filter comprises a Key's interpolation filter which is implemented on Haar wavelet coefficients.

108. The method defined in Claim 107 wherein performing resampling using an interpolation filter comprises computing an overcomplete transform and critically sampling coefficients.

109. The method defined in Claim 107 wherein the Key's interpolation filter performs the following procedure on wavelet coefficients:

x_int = $(a_0 + a_1 + a_2 + a_3)s_i^2 + (a_0 + a_1 - a_2 - a_3)d_i^2 + (a_0 - a_1)d_i^1 + (a_2 - a_3)d_{i+1}^1$.

110. A method comprising:

applying a forward wavelet transform to image data;

performing a filtering operation on coefficients with a coefficient domain operator; and

applying an inverse wavelet transform to coefficients after filtering.

111. The method defined in Claim 110 wherein performing a filtering operation comprises filtering a subband at a specific level decomposition to modify the single subband.

112. The method defined in Claim 111 wherein performing a filtering operation comprises filtering the LL component at the largest decomposition level with a sharpening filter.

113. The method defined in Claim 111 wherein performing a filtering operation comprises filtering the LL component at the largest decomposition level with a smoothing filter.

114. The method defined in Claim 110 wherein performing a filtering operation comprises removing periodic patterns in a specific band by applying a filter to the specific band.

115. The method defined in Claim 114 wherein the filter comprises a band pass filter.

116. The method defined in Claim 114 wherein the filter comprises a notch filter.

117. The method defined in Claim 110 wherein the period is 3.

118. The method defined in Claim 110 wherein the period is 5.

119. A copier having a wavelet-based image processing path for enhancing image data.

120. A printer having a wavelet-based image processing path for enhancing image data.